Enhanced 3DNow!™ Technology for the AMD Athlon™ Processor

Enabling a Superior 3D Visual Computing Experience for Next-Generation x86 Computing Platforms

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Introduction: Taking 3DNow!™ Technology to the Next Level

3DNow!™ technology has proven to be a significant addition to the x86 architecture that drives today's computing platforms. Introduced as a key feature of the AMD-K6®-2 processor in May 1998, 3DNow! technology has a growing worldwide installed base of more than 15 million PCs (as of mid-1999). With the introduction of 3DNow! technology, AMD became the first company to deliver a 3D enhancement instruction set for x86 platforms, as well as the first to introduce superscalar SIMD floating point technology for x86 processors. Intel delivered its SIMD floating point solution (SSE) nine months *after* the advent of 3DNow! technology.

SIMD, which stands for Single Instruction Multiple Data, enables a single instruction to operate in parallel on multiple pieces of data. The original 3DNow! technology consists of 21 instructions that enhance the personal computing experience by using SIMD floating point techniques to open the processing bottlenecks for floating point-intensive and multimedia applications. 3DNow! instructions are designed to improve the performance of single-precision floating point operations, enabling up to four of these operations to execute in a single clock cycle.

3DNow! technology-optimized hardware and software applications can be used to create more productive, visually realistic, and entertaining PC platforms. 3DNow! technology enables faster frame rates on high-resolution video scenes, better physical modeling of real-world environments, sharper and more detailed 3D imaging, smoother video playback, and theater-quality audio. The result is a more satisfying visual computing experience.

With the introduction of the AMD Athlon™ processor, AMD has taken 3DNow! technology to the next level of performance and functionality. The AMD Athlon processor features an enhanced version of 3DNow! technology that adds 24 instructions to the existing 21 original 3DNow! instructions. These 24 additional instructions include:

- 12 instructions that improve multimedia-enhanced integer math calculations used in such applications as speech recognition and video processing
- 7 instructions that accelerate data movement for more detailed graphics and new functionality for Internet browser plug-ins and other streaming applications, enabling a richer Internet experience
- 5 DSP instructions that enhance the performance of communications applications, including soft modems, soft ADSL, MP3, and Dolby Digital surround sound processing. This DSP functionality is unique to the AMD Athlon processor and not supported by Intel's Pentium® III processor.

In enhancing 3DNow! technology, AMD kept the instruction set design simple, yet powerful. AMD's goal in designing these additional 3DNow! instructions was to provide powerful SIMD performance at least comparable to SSE while enabling ease of implementation for software developers. The relatively few instructions of enhanced 3DNow! technology (a total of 45 instructions versus SSE's 71), as well as full support by various compilers and debuggers, allow developers to adopt this technology and optimize their applications quickly. In addition to the 24 additional 3DNow! instructions, the AMD Athlon processor implements microarchitecture enhancements that enable more efficient operation of all these instructions, resulting in fewer coding restrictions and greater programming efficiencies.

Table 1 below compares the instructions implemented in 3DNow! technology and SSE. 3DNow! technology is the superior solution because it was first to market and continues to have tremendous momentum with a large installed base. It also offers the latest SIMD extensions, as well as new DSP functionality not available in SSE, and enables enhanced 3D/multimedia performance that is planned to provide tangible end-user benefits for years to come.

Table 1: Enhanced 3DNow!™ Technology vs. SSE – Instruction Comparison

Functionality	3DNow!™	SSE	Conclusion
SIMD floating point functionality (an AMD first)	21 (original 3DNow! instructions)	~52	**Comparable functionality**: Both technologies support 4 FP operations per clock. But 3DNow! technology is simpler to implement. SSE has many more instructions because Intel's architecture requires MMX™ control functionality to be duplicated and requires two FP instructions per extension: one for SIMD and another for scalar operations.
MMX™ (integer) augmentation and data movement	19 (additional instructions)	19	**Comparable functionality**: Both have instructions for cache and streaming controls.
DSP/communication extensions	5 (additional instructions)	0	**Unique AMD functionality**: AMD advances SIMD with DSP extensions for soft modems, soft ADSL, complex math, MP3, and Dolby Digital.
Total number of instructions	45	71	**Advantage AMD:** Enhanced 3DNow! technology has greater functionality than SSE. When combined with the superior FP engine in the AMD Athlon processor, the result is the best FP/multimedia performance in x86 processors.

24 New 3DNow!™ Instructions Added to the AMD Athlon™ Processor

As described in the introduction, the 24 multimedia instructions added to the enhanced 3DNow! technology implemented in the AMD Athlon processor fall into three categories:

- 12 extensions to augment the MMX™ instruction set – more accurate speech recognition software and high-quality video encoding/decoding applications (*see Table 2 in Appendix A*)
- 7 data movement/streaming instructions – enhanced performance of many software applications and the ability to move large amounts of multimedia data into and out of the processor, enabling improved data movement for Internet plug-ins and other streaming applications (*see Table 3 in Appendix A*)
- 5 DSP/communications extensions – faster processing of communications-based applications, such as soft modems, cable modems, and ADSL modems, as well as advanced audio applications, such as MP3 and Dolby Digital surround sound (*see Table 4 in Appendix A*).

A Superior Implementation for 3D Enhancement

The AMD Athlon processor's seventh-generation microarchitecture is well suited to the new multimedia extensions implemented in the processor, as well as the original 3DNow! instruction set. In developing the original 3DNow! technology, AMD kept the instruction set design sparse, yet powerful. AMD's goal was to provide powerful SIMD performance while enabling ease of implementation for software developers.

The relatively few instructions of 3DNow! technology allow developers to adopt this technology and optimize their applications quickly and easily. Likewise, the new multimedia enhancement, data movement, and DSP extensions implemented in the AMD Athlon processor are designed to handle the computation requirements of complex multimedia applications, and yet the total number of instructions is still manageable enough to allow easy, efficient programming.

More Efficient Multimedia Execution with 2-Way SIMD

The SIMD technique implemented in the enhanced 3DNow! technology involves one instruction acting upon multiple data values. 3DNow! instructions can operate on two 32-bit values at a time. This 2-way SIMD approach matches the 64-bit execution unit size in the AMD Athlon processor, which enables very efficient use of the multimedia execution resources.

The AMD Athlon processor can generate four 32-bit floating point results (adds, subtracts, multiplies) per clock cycle. Each instruction not only operates on two single-precision floating point operands, but the AMD Athlon processor microarchitecture can also execute up to two 3DNow! instructions per clock cycle through two execution pipelines. The flexible microarchitecture can allow future AMD Athlon processor implementations to be augmented with additional pipelines. The AMD Athlon processor also has separate Add and Multiply hardware, which enables it to perform simultaneous floating point add and multiply calculations.

The multimedia units in the AMD Athlon processor are fully pipelined and can execute most of the additional multimedia enhancement and 3DNow! technology extensions in a single cycle. Other implementations (such as the Pentium III) whose 4-way SIMD approach and 64-bit execution unit size do not match, require a 2-pass technique to execute some of their multimedia instructions.

The AMD Athlon processor's 2-way SIMD approach saves programmers from having to painstakingly restructure their data arrays to match 4-way SIMD architectures (as used in the Pentium III). Exploitation of 4-way SIMD requires total rearrangement of data structures, which can have wide-ranging impact on an entire software project and may impact non-program-related content. Software developers can continue to use their existing data structures, which are more effectively exploited with 2-way SIMD technology than with 4-way SIMD, enabling them to focus more of their time on providing richer content. When processing vectors with lengths of four or more values, the AMD Athlon processor can fully exploit its superior execution and data movement resources, enabling it to outperform previous-generation x86 processors, such as the Pentium III.

In addition, the Direct3D application programming interface (API) in Microsoft's DirectX 7.x contains data structures that provide a better match for the 2-way SIMD approach of enhanced 3DNow! technology. In short, 2-way SIMD involves much less shuffling of data than 4-way SIMD, with no performance degradation.

How the AMD Athlon™ Processor Architecture Benefits Data Movement

Many multimedia algorithms require the movement of large data sets into the processor for manipulation and then out of the processor to the video card for display. To realize the benefits of the added data movement instructions, the processor must offer the necessary microarchitecture features and bandwidth. The AMD Athlon processor's deep internal buffering and pipelines enable very high operating frequencies.

The AMD Athlon processor's extremely large 128KB L1 cache holds much more data than the smaller (32KB) L1 cache of Pentium III, enabling the AMD Athlon processor to access its data more rapidly than competing processors. In addition, the AMD Athlon processor brings in data in 64-byte cache blocks—twice the size of the Pentium III. The AMD Athlon processor also features an on-die 256KB L2 cache that enables the L2 cache to run at the same frequency as the processor.[1] The L2 cache is organized as a 16-way set associative design, allowing an improved hit ratio for sophisticated data structures. In addition to this extremely high-bandwidth interface, the AMD Athlon processor uses an "exclusive" L2 cache design which improves L2 efficiency by excluding L1 data from the L2 cache. Most L2 caches utilize an "inclusive" design, forcing the L2 cache to include or store redundant data the L1 cache already has in storage. This redundancy in storage reduces the total amount of information the L2 cache can use to store other important data. The AMD Athlon processor has a total of 128KB+256KB=384KB of full-speed on-die cache—a total system cache more than 95KB larger than that of the Pentium III.

The enhanced 3DNow! technology, 200MHz system bus, full-speed on-die L2 cache, superscalar floating point engine, and other seventh-generation architectural features of the AMD Athlon processor all contribute to the processor's ability to move data faster and more efficiently than previous-generation implementations, such as the Pentium III.

Zero Switching Overhead

The AMD Athlon processor imposes no switching overhead between executing x87 (floating point) and 3DNow! instructions. This allows developers to port to 3DNow! technology without fear of performance degradation when they switch back to any required x87 code. Because there is no switching overhead between x87 and MMX instructions, MMX or 3DNow! instructions can easily be added to existing applications.

No New Operating System Support Needed

Enhanced 3DNow! technology allows 3DNow! and MMX registers to be shared. Therefore, the enhanced 3DNow! instruction set does not require new operating system support, which enables compatibility with Microsoft® Windows® and many other popular operating systems, such as Linux and Solaris. Adding new registers contributes to the

[1] While all AMD Athlon processors currently in production feature 256K of full-speed, on-die L2 cache memory, previous versions without on-die L2 cache may still be commercially available.

complexity of maintaining yet another processor state and subsequent context switching overhead.

Sharing 3DNow! and MMX registers also provides the benefit of being able to use MMX instructions to load/store, shuffle, and compare 3DNow! instruction data. For example, a programmer can use MMX instructions to quickly extract the exponents and mantissas in Exp and Log functions directly from 3DNow! instruction data.

Powerful Instruction Decoders

The AMD Athlon processor has high instruction decode bandwidth to enable efficient operation of 3DNow! instructions. The AMD Athlon processor contains three powerful instruction decoders, which are fed by an instruction cache four times larger than the Pentium III instruction cache. Each decoder can decode any type of instruction, enabling it to decode up to three 3DNow! instructions per cycle. The Pentium III processor can only decode one 4-way SSE type instruction per cycle because it has only one complex decoder.

The combination of the sophisticated instruction decoders and the dual load/store pipes in the AMD Athlon processor enables 3DNow! instructions that access memory to execute without affecting the peak throughput of other 3DNow! instructions. This is a much more efficient and more scalable alternative to adding registers or register space.

New DSP Instructions Unique to the AMD Athlon™ Processor

The majority of digital signal processing (DSP) instructions are represented by four algorithms: complex arithmetic multiplies, FIR filter evaluation, FFT/DFT, and Reed-Solomon error correction code. The five new DSP extensions added to 3DNow! technology greatly accelerate the execution of these algorithms, enabling low-cost implementations of communications products, such as ADSL, cable, and V.90 modems, as well as advanced audio applications, such as MP3 and Dolby Digital surround sound. The AMD Athlon processor is currently the only x86 processor that offers instructions specifically designed to enhance DSP/communications applications.

A More Efficient Approach to Prefetching

In addition to supporting the various flavors of the new streaming PREFETCH instructions, the AMD Athlon processor implements 3DNow! technology's PREFETCHW instruction for intent-to-modify purposes. When the programmer wants to modify the

prefetched data, other existing x86 processors would have to prefetch the instruction and then issue a write operation. This write operation changes the cache state to "Modified," which causes additional cycles to be consumed. By using the PREFETCHW instruction in the AMD Athlon processor, the data is brought in and simultaneously marked as "Modified." This efficient approach to prefetching ultimately enhances multimedia performance by saving 15 to 25 cycles over the less-efficient technique of handling the cache state change after issuing the write. These saved cycles mean the program can run faster, which ultimately helps enhance the user's computing experience.

Summary: Making a Powerful 3D Technology Even Better

By enhancing 3DNow! technology for the AMD Athlon processor architecture, AMD has made a powerful technology even better. The additional features and instructions added to the AMD Athlon processor will allow even greater numbers of software programs (and therefore users) to benefit from the enhanced performance enabled by the added instructions. In addition, more types of programs can now use these instructions, and therefore emerging technologies such as voice-recognition, digital video, enhanced Internet audio and video streaming, and digital communication will become more commonly available to broader audiences.

3DNow! technology's high performance and operating system friendliness has enabled AMD to garner widespread software support while providing tangible benefits to many existing customers who use AMD processors with 3DNow! technology. Support for 3DNow! technology exists today in the leading industry-standard APIs, including Microsoft's DirectX 7.x and SGI's OpenGL. In addition, numerous applications from leading independent software vendors (ISVs) worldwide have been or are in the process of being optimized for 3DNow! technology.

The proliferation of AMD Athlon processor-based platforms is planned to enhance the growth and vitality of the 3DNow! technology installed base by opening the door to a wider range of markets, including the small business and commercial enterprise segments. AMD processors with 3DNow! technology are planned to span the complete range of x86 computing platforms, from sub-$1,000 PCs and laptops based on the AMD-K6-2 processor to high-end desktop systems, workstations, and servers powered by the AMD Athlon processor.

Now and in the future, the AMD Athlon processor with enhanced 3DNow! technology is planned to deliver a superior 3D visual computing experience for the next generation in x86 computing platforms.

AMD Overview

AMD (NYSE: AMD) is a global supplier of integrated circuits for the personal and networked computer and communications markets. AMD produces processors, flash memories, and products for communications and networking applications. The world's second-leading supplier of Windows compatible processors, AMD has shipped more than 120 million x86 microprocessors, including more than 90 million Windows compatible CPUs. Founded in 1969 and based in Sunnyvale, California, AMD has sales and marketing offices worldwide and manufacturing facilities in Sunnyvale; Austin, Texas; Dresden, Germany; Bangkok, Thailand; Penang, Malaysia; Singapore; and Aizu-Wakamatsu, Japan. AMD had revenues of $2.9 billion in 1999.

Cautionary Statement

This White Paper includes forward-looking statements that are made pursuant to the safe harbor provisions of the Private Securities Litigation Reform Act of 1995. Forward-looking statements are generally preceded by words such as "expects," "plans," "believes," "anticipates," or "intends." Investors are cautioned that all forward-looking statements in this white paper involve risks and uncertainties that could cause actual results to differ from current expectations. Forward-looking statements in this white paper about the AMD Athlon processor involve the risk that AMD will not be able to produce the processor in the volume required by customers on a timely basis; that AMD may not be successful in developing an infrastructure to support the processor; that third parties may not provide infrastructure solutions to support the processor; that the processor will not achieve customer and market acceptance; and that software applications will not be optimized for use with the processor. We urge investors to review in detail the risk and uncertainties in the company's Securities and Exchange Commission filings, including the most recently filed Form-10K.

Appendix A

24 New Instructions of Enhanced 3DNow!™ Technology

Table 2: Multimedia Extensions

Instruction	Function
PAVGB	Packed average of unsigned byte
PAVGW	Packed average of unsigned word
PEXTRW	Extract word into integer register
PINSRW	Insert word from integer register
PMAXSW	Packed maximum signed word
PMAXUB	Packed maximum unsigned byte
PMINSW	Packed minimum signed word
PMINUB	Packed minimum unsigned byte
PMOVMSKB	Move mask to integer register
PMULHUW	Packed multiply high unsigned word
PSADBW	Packed sum of absolute byte differences
PSHUFW	Packed shuffle word

Table 3: Data Movement/Streaming Instructions

Instruction	Function
MASKMOVQ	Streaming store using byte mask
MOVNTQ	Streaming store
PREFETCHNTA	Prefetch non-temporal access
PREFETCHT0	Prefetch to all cache levels
PREFETCHT1	Prefetch to all cache levels except 0 level
PREFETCHT2	Prefetch to all cache levels except 0 and 1st level
SFENCE	Store fence

Table 4: DSP/Communications Extensions

Instruction	Function
PF2IW	Packed floating point to integer word conversion with sign extend
PFNACC	Packed floating point negative accumulate
PFPNACC	Packed floating point mixed positive-negative accumulate
PI2FW	Packed integer word to floating point conversion
PSWAPD	Packed swap double word

Appendix B

21 Original Instructions of 3DNow!™ Technology

Table 5: Floating Point Instructions

Instruction	Function
PAVGUSB	Packed 8-bit unsigned integer averaging
PFADD	Packed floating point addition
PFSUB	Packed floating point subtraction
PFSUBR	Packed floating point reverse subtraction
PFACC	Packed floating point accumulate
PFCMPGE	Packed floating point comparison, greater or equal
PFCMPGT	Packed floating point comparison, greater
PFCMPEQ	Packed floating point comparison, equal
PFMIN	Packed floating point minimum
PFMAX	Packed floating point maximum
PI2FD	Packed 32-bit integer to floating point conversion
PF2ID	Packed floating point to 32-bit integer
PFRCP	Packed floating point reciprocal approximation
PFRSQRT	Packed floating point reciprocal square root approximation
PFMUL	Packed floating point multiplication
PFRCPIT1	Packed floating point reciprocal first iteration step
PFRSQIT1	Packed floating point reciprocal square root first iteration step
PFRCPIT2	Packed floating point reciprocal/reciprocal square root second iteration step
PMULHRW	Packed 16-bit integer multiply with rounding

Table 6: Performance-Enhancement Instructions

Instruction	Function
FEMMS	Faster entry/exit of the MMX™ technology or floating point state
PREFETCH	Prefetch at least a 32-byte line into L1 data cache (Dcache)